

**ELECTRICAL CONDUCTIVITY IN
MAGNESIUM-DOPED Al_2O_3 CRYSTAL AT
MODERATE TEMPERATURES.**

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AC and DC electrical measurements between 273 and 800 K were used to characterize the electrical conductivity of $Al_2O_3:Mg$ single crystals containing $[Mg]^0$ center. At low fields contacts are blocking. At high fields, electrical current flows steadily through the sample and the I-V characteristic corresponds to a directly biased barrier with a series resistance (bulk resistance). AC measurements yield values for the junction capacitance as well as for the sample resistance, and provide perfectly reproducible conductivity values. The conductivity varies linearly with the $[Mg]^0$ concentration and a thermal activation energy of 0.68 eV was obtained, which agrees very well with the activation energy previously reported for motion of free holes.

Key words: Electrical conductivity, $[Mg]^0$, center, $Al_2O_3:Mg$

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1 INTRODUCTION

MgO crystals containing $[Li]^0$ centers (substitutional Li^+ ions, each attended by a hole), have been shown to be p-type semiconducting, with an acceptor level of 0.7 eV [1]-[5]. By analogy, substitutional Mg^{2+} in Al_2O_3 is also attended by hole [6, 7] and expected to serve as a p-type semiconductor. Both $MgO:Li$ and $Al_2O_3:Mg$ systems have potential as high-temperature p-type semiconductors. However whereas the former is brittle and will have limited application, the latter is expected to have better mechanical integrity. In the present study, AC and DC electrical measurements were used to characterize the electrical conductivity of $Al_2O_3:Mg$ single crystal containing $[Mg]^0$ center after oxidation at elevated temperatures.

2 EXPERIMENTAL PROCEDURE

$Al_2O_3:Mg$ crystal were grown by the Czochralski method. Atomic Emission Spectrometry analyses indicated that the magnesium concentration was 25ppm. Samples were polished to optical transparency. The c axis was parallel to the broad face of the sample. Electrodes were made by sputtering several metals with different work functions (Mg , Al and Pt) onto the samples surfaces, and the electrical field was applied perpendicular to the c axis. The same response was observed regardless of contact electrode materials. Optical absorption measurements were made with Perkin Elmer Lambda 19 spectrophotometer.

3 RESULTS AND DISCUSSION

Single crystal of $Al_2O_3:Mg$ are colorless after heating at $T > 950$ K in a reducing atmosphere. However they become gray-purple after oxidation at $T > 1200$ K [7, 8]. This coloration is due a broad asymmetric optical adsorption band, centered at ≈ 2.5 eV (496 nm), and has been attributed to Mg^{2+} cations, each with a trapped hole localized on one of the six NN oxygen ions. These defects are paramagnetic and are referred to as $[Mg]^0$ centers [3, 4].

Electrical conductivity measurements between 273 – 800 K were made in $Al_2O_3:Mg$ crystal containing $[Mg]^0$ centers. DC electrical measurements at low fields revealed blocking contacts. However, at high fields, the reverse bias characteristic is that of a "soft" barrier, and the I-V characteristic of the sample corresponds to a directly biased barrier with a series resistance, R_s , (bulk resistance), regardless of the polarity of the applied voltage (Fig.1).

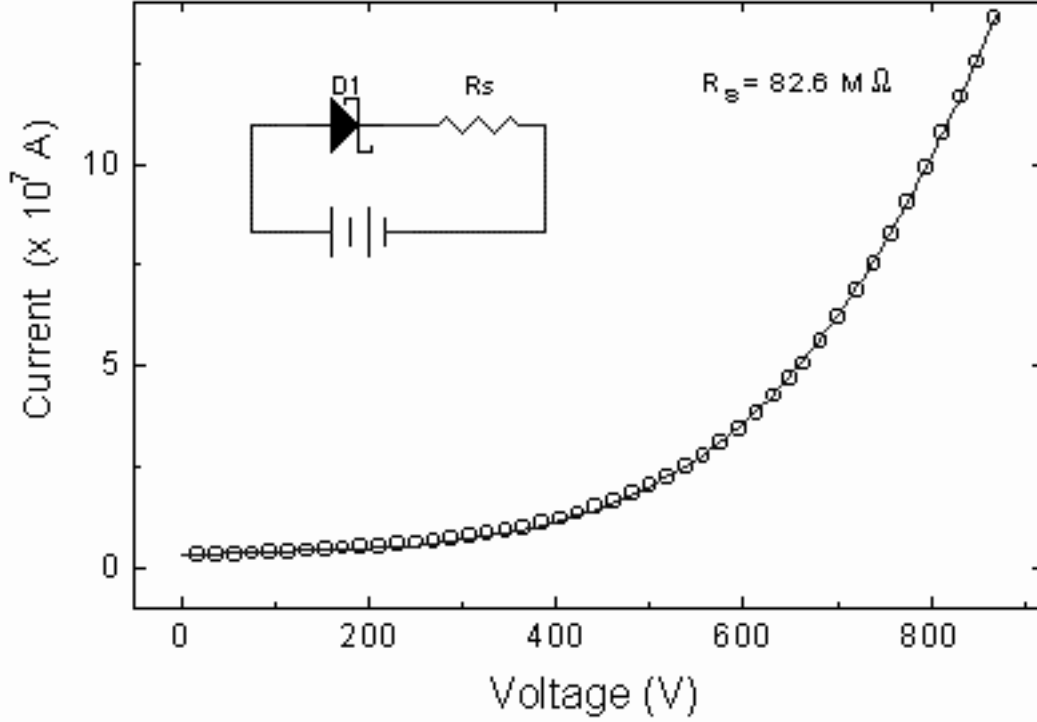


Figure 1: Direct current I-V characteristic at 313 K for an $Al_2O_3:Mg$ crystal containing $[Mg]^0$ centers. The solid line represents the best fit of experimental points to a directly biased barrier with a series resistance.

The results of low voltage AC measurements reinforce the DC interpretation and yield values for the junction capacitance as well as for the sample resistance. Fig. 2, shows a log-log plot of impedance the applied voltage frequency for a low voltage ($\approx 1V$). Three frequency regions are observed, consistent with a series combination of a capacitance (C_s), with a resistance (R_s), and both connected in parallel with a capacitance (C_p). In Fig.2, the corresponding impedances of C_s , R_s , C_p dominate the low, intermediate and high frequency region, respectively. The resulting value for C_p agrees with the capacity of a parallel-plate condenser with the Al_2O_3 dielectric constant. R_s is in good agreement with the value derived from Al_2O_3 I-V characteristic.

Lastly a C_s value of the order of a nF seem to be reasonable for a sample with a cross section of $25mm^2$.

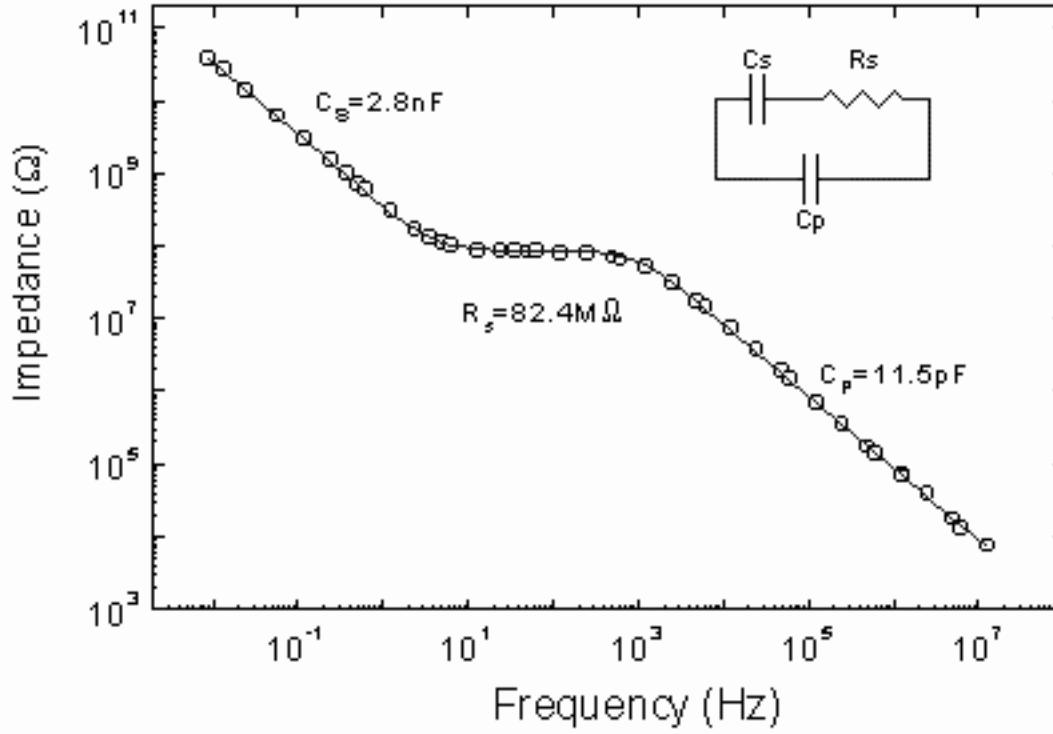


Figure 2: Log-log of impedance versus frequency at 313 K for an $Al_2O_3:Mg$ crystal containing $[Mg]^0$ centers. The solid line represents the best fit of the experimental points to the equivalent circuit.

AC measurements provide perfectly reproducible conductivity values. At a fixed temperature, the conductivity varies linearly with the $[Mg]^0$ concentration (Fig. 3). From the temperature dependence of the conductivity, a thermal activation energy of 0.68 eV was obtained, which agrees very well with the activation energy for the motion of free holes as large polarons [7].

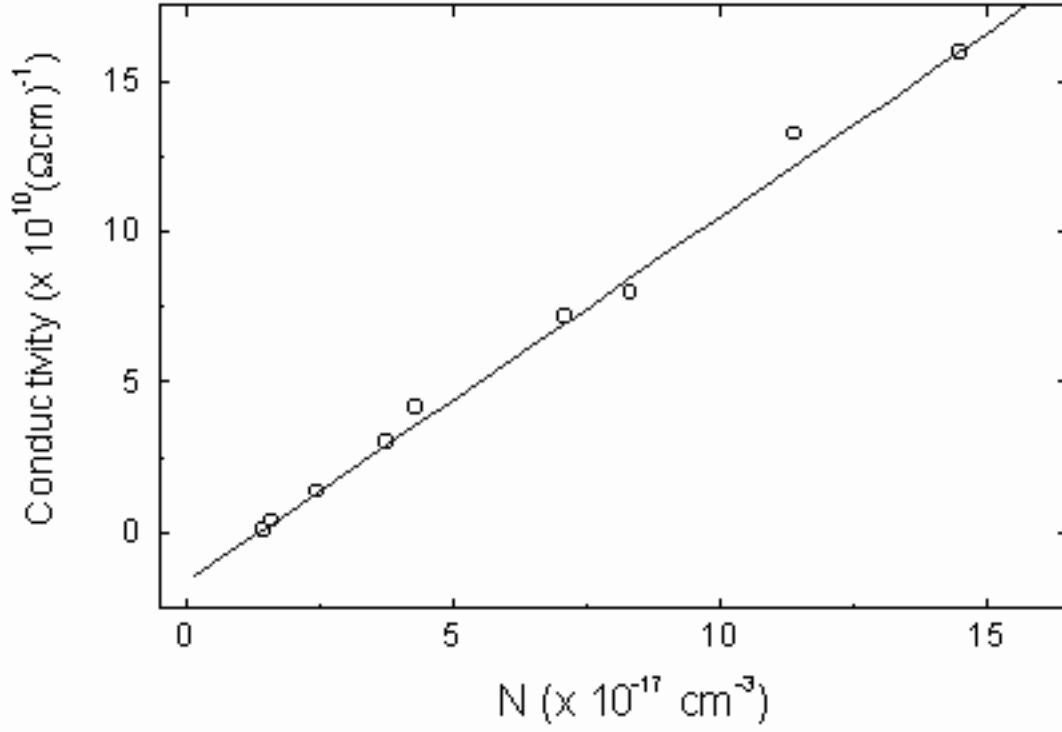


Figure 3: Conductivity versus concentration of $[Mg]^0$ centers at $T=313$ K. The concentration values were determined from the peak of the optical absorption band at 2.5 eV associated with the $[Mg]^0$ centers [7].

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References

- [1] M.M Abraham, Y. Chen, L.A. Boatner and R.W. Reynolds, *Phys. Rev. Lett.* **37**, 849 (1976).

- [2] Y. Chen, H.T. Tohver, J. Narayan and M.M. Abraham, *Phys. Rev.* **B16**, 5535 (1977).
- [3] D. J. Eisenberg, L. S. Cain, K. H. Lee and J. H. Crawford, *Jr. Appl. Phys. Lett.* **33**, 479 (1978).
- [4] Y. Chen, R. H. Kernohan, J. L. Boldù, M. M. Abraham, D. J. Eisenberg and J. H. Crawford, *Jr. Solid State Commun.* **33**, 441 (1980).
- [5] R. Ramírez, R. González, R. Pareja and Y. Chen, *Phys. Rev.* **B55**, 2413 (1997).
- [6] R. T. Cox, *Solid State Commun.* **9**, 1989 (1971).
- [7] H.A. Wang, C.H. Lee, F. A. Kroger and R.T. Cox, *Phys. Rev.* **B27**, 3821 (1983).
- [8] R. Vila and M. Jiménez de Castro and R.T. Cox, *Phys. Rev.* **B49**, 1696 (1994).